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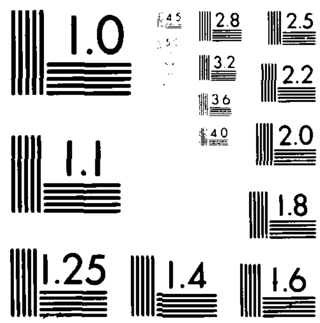

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TWCP ELECTRON BEAM TESTING PROGRAM

Volume II—Preliminary Characterization of the Blackjack III Pulsed Electron Beam for Material Response Studies

ADA086306

Effects Technology, Inc.
5383 Hollister Avenue
Santa Barbara, California 93111

5 Apr[redacted]79

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ETI-CR79-610-Vol-2

Final Report, [redacted] Jul[redacted]77—Dec[redacted]78

F. A. Bick

CONTRACT Nos. DNA 001-76-C-0357,
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DNA 5036F-2	2. GOVT ACCESSION NO. AD-A086 306	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) TWCP ELECTRON BEAM TESTING PROGRAM Volume II—Preliminary Characterization of the Blackjack III Pulsed Electron Beam for Material Response Studies		5. TYPE OF REPORT & PERIOD COVERED Final Report for Period Jul 77—Dec 78
		6. PERFORMING ORG. REPORT NUMBER CR79-610
7. AUTHOR(s) Compiled and Edited by F. A. Bick		8. CONTRACT OR GRANT NUMBER(s) DNA 001-76-C-0357 DNA 001-78-C-0063
9. PERFORMING ORGANIZATION NAME AND ADDRESS Effects Technology, Inc. 5383 Hollister Avenue Santa Barbara, California 93111		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Subtask N99QAXAH116-01
11. CONTROLLING OFFICE NAME AND ADDRESS Director Defense Nuclear Agency Washington, D.C. 20305		12. REPORT DATE 5 April 1979
		13. NUMBER OF PAGES 40
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B342078464 N99QAXAH11601 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pulsed Electron Beam Testing	Impulse Measurements
Tape Wrapped Carbon Phenolic (FM5822A)	Stress Measurements
Phenolic Resin (91-LD)	Material Response Testing
Impulse and Stress Generation	TWCP Correlation Program

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Volume II of four volumes. This volume describes the preliminary characterization of the Maxwell Laboratory Blackjack III pulsed electron beam facility as to energy spectrum, depth-dose profiles and fluence levels and uniformity. These tests were conducted preparatory to obtaining impulse and stress generation data on FM5822A carbon phenolic, and 91-LD phenolic resin. These tests demonstrated the capabilities of the Blackjack III facility for material response studies for peak electron energies of 0.7 to 1.0-MeV with fluence levels less than 200 cal/cm^2.

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19. KEY WORDS (Continued)

Nuclear Hardness Evaluation Procedures Program
Blackjack III Electron Beam Facility
Blackjack III Electron Beam Characterization
Electron Beam Diagnostics
In-Situ Calorimetry
Depth-Dose Measurements

PREFACE

This work was done for Effects Technology, Inc. (ETI) under the sponsorship and guidance of Mr. Donald Kohler of the Defense Nuclear Agency (DNA). The ETI purchase orders to CAPCo and to Maxwell Laboratories, Inc., were P.O. 6204 and P.O. 6193, respectively. The DNA funding to ETI for the entire activity was under Contract No. DNA001-76-C-0357. The ETI program manager was Mr. M. J. Rosen.

General program planning and execution was accomplished jointly with the participation of the following individuals and organizations:

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We would like to acknowledge contributions made by Drs. J. E. Rauch and P. Korn of MLI, Mr. A. Lutze of the Stanford Research Institute and Mr. K. Childers of Physics International Company. Data reduction and analysis assistance was provided by Ms. Carhart (AFWL) and Mr. W. Foreman (CAPCo).

This is the second volume of a four volume set describing the electron beam experiments in support of the TWCP Correlation Program. The four volumes are:

TWCP Electron Beam Testing Program:
Volume I - Summary

TWCP Electron Beam Testing Program:
Volume II - Preliminary Characterization of the Blackjack III Pulsed Electron Beam for Material Response Studies

TWCP Electron Beam Testing Program:
Volume III - Material Response Instrumentation for The Blackjack III Pulsed Electron Beam Facility

TWCP Electron Beam Testing Program:
Volume IV - Electron Beam Tests in Support of The TWCP Correlation Program

These volumes were compiled and edited by Effects Technology, Inc. (ETI). Volume I was written by ETI, drawing upon the material in Volumes II, III and IV which were written by Corrales Applied Physics Company under subcontract to ETI.

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SECTION 1

INTRODUCTION AND SUMMARY

The principal objective of the tests described in this report was to characterize the electron beam from the Maxwell Blackjack III accelerator to determine the feasibility of using it for material response experimentation. Prior to testing it was determined that a beam having about a 1-MV peak accelerating voltage was desired.* It was further desired that the beam be characterized in terms of depth-dose and fluence distribution at two peak fluence levels--approximately 100-and 200-cal/cm^2.

This characterization was accomplished with eight days of pulsing between the 11th and 22nd of July 1977; a total of 68 shots were obtained exclusive of calibration pulses. Table 1 summarizes the overall distribution and nature of these tests. To accomplish the characterization it was necessary to investigate a number of machine configurations which utilized various cathodes, anode-cathode gaps, and

*The relative desirability of this electron beam condition, in comparison to other achievable conditions on the Blackjack III machine, was ascertained from sensitivity analyses that consisted of determining the relative accuracy of assigning numerical values or functional relationships to the critical model parameters for impulse and stress-time calculations (expressed usually with respect to deposited energy). As a sidepoint, peak accelerating voltages in excess of the present maximum of approximately 1-MV from the Blackjack III machine would be even more desirable.

Table 1. Summary of Representative Operating Conditions.

Shot Nos.	Cathode Diameter (cm)	Anode-Cathode Gap (mm)	Peak Diode Voltage (MV)	Fluence* (cal/cm^2)
1574-1594	25	8.5	0.8	40
1595-1598	13	6.8	0.9	100
1599-1612	22	10.0	0.7	50
1613-1651**	10	6.4	1.0	120

*Average over 10-cm^2, anode-calorimeter distance = 65-cm.

**Ten pulses (1634-1643) in this sequence were part of another program.

switch gaps, which yielded peak diode voltages between 0.7- and 1.0-MV. Characterization data were obtained for peak voltages less than 1-MV, but these data are not included in this report since the 1-MV peak voltage beam condition was analytically determined to be more desirable for the anticipated material response experiments. All tests were performed with a Marx generator charge voltage of 60-kV. The beam transport between cathode and target was controlled with a 5- to 30-kG axial magnetic field. It was also necessary to interface and debug beam diagnostics which were new to the Maxwell facility; namely, depth-dose and fluence calorimeters, a filtered Faraday cup, and a passive momentum gauge (to measure anode debris impulse).

The characterization data presented in the next section of this report are based on the detailed analysis of 20 consecutive shots taken over a three day period. Machine parameters were held fixed during this period in order to evaluate beam reproducibility. The following average diode characteristics were obtained:

Peak voltage	1.0 MV
Peak current	560 kA
Total energy	32 kJ
Power pulse width (FWHM)	58 nsec
Mean electron energy	720 keV

The radial fluence distributions for two levels (174- and 122-cal/cm^2 average fluence over 10-cm^2) are shown in Figure 1. Figure 2 shows the depth-dose characteristic which was measured at the 122-cal/cm^2 level, which is consistent with transport calculations for electrons incident at 30-degrees, and indicates a peak relative dose of 4.2-(cal/gm)/(cal/cm^2) and 0.4-gm/cm^2 electron range.

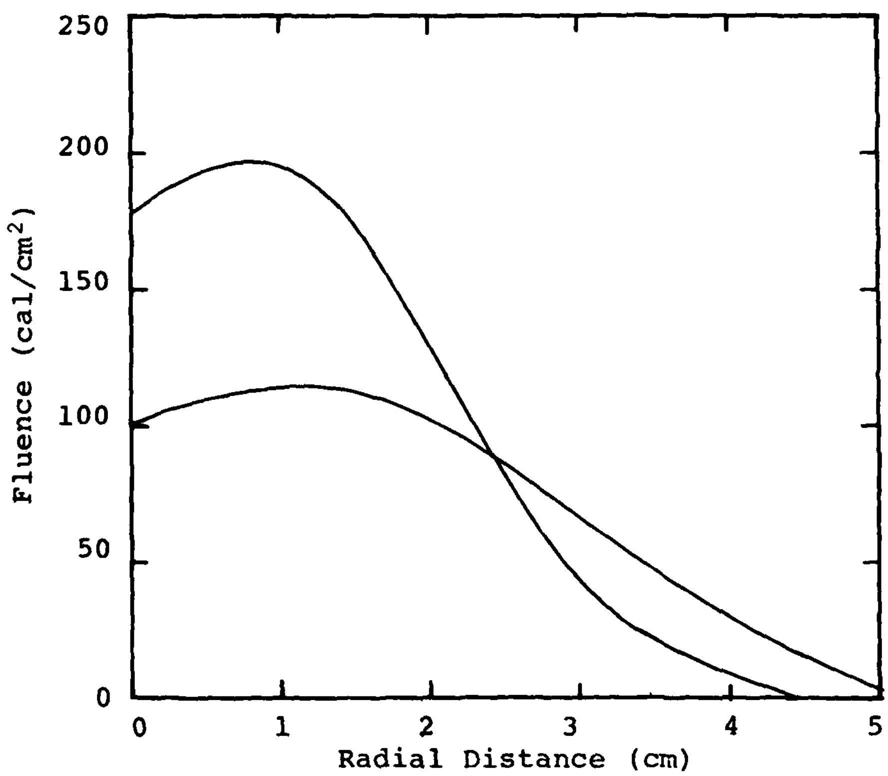

Figure 1. Radial Fluence Distributions for 122-and 174-cal/cm^2 Levels.

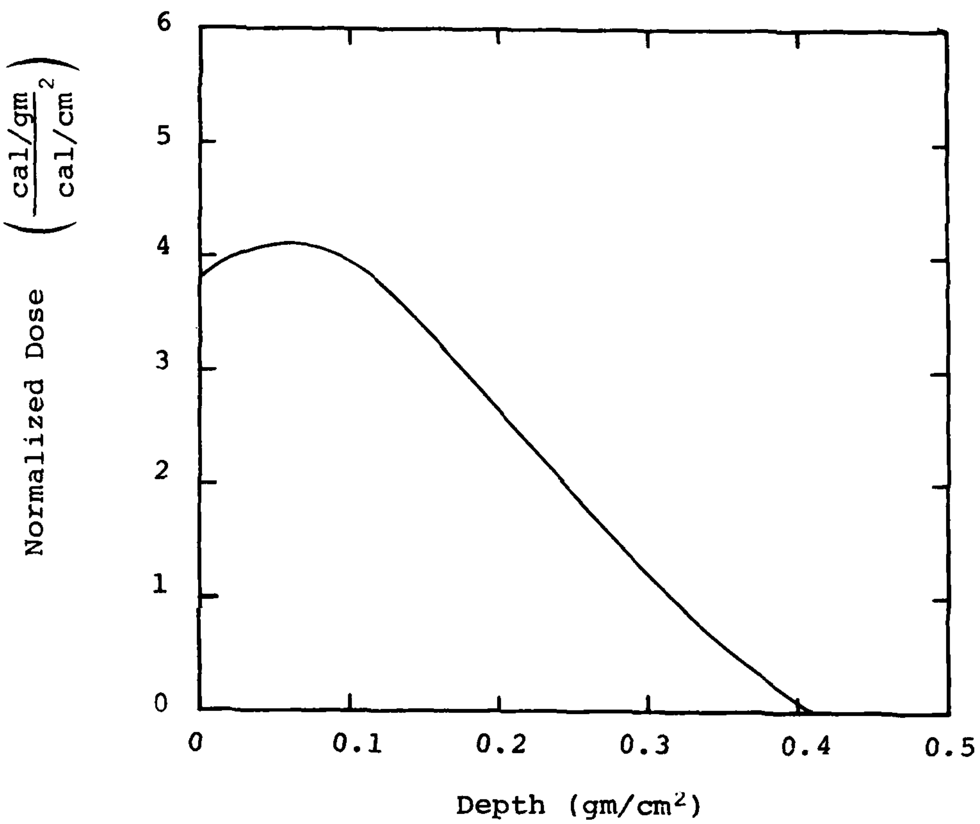

Figure 2. Depth-Dose Characteristics.

SECTION 2

CHARACTERIZATION DATA

The diode, depth-dose, and fluence data presented here were obtained on the 20 consecutive shots summarized in Table 2. The diode current and voltage data from each test were digitized and used to compute the total diode energy, deposition time or power pulse width (FWHM), and spectrum. Diode current and voltage data from a representative shot are given in Figure 3, and the resulting typical spectrum is shown in Figure 4. In general the spectra tend to be simply shaped and relatively mono-energetic with about 80 percent of the energy between 0.8-and 1.0-MeV.

The depth-dose calorimeter consisted of disk-shaped nominally 0.01- and 0.02-inch thick, ATJ graphite elements, with thermocouples attached at the circumference. An exponential extrapolation of an analytic fit to the first 20 to 30 seconds of the recorded temperature versus time data was used to determine the temperature of each calorimeter element. Dose was computed from the following relationship: $E = \int C_p dT$ where the ATJ graphite specific heat capacity is:

$$C_p = 0.150 + 7.82 \times 10^{-4} T - 7.51 \times 10^{-7} T^2 + 2.78 \times 10^{-10} T^3$$

with C_p in cal/g-°C and T in °C.

Table 2. Data for Twenty Consecutive Pulses

Shot No.	Depo. Time (nsec)	Diode Energy (kJ)	Mean Electron Energy (keV)	Peak Diode Voltage (MV)	Peak Diode Current (kA)	Average Fluence 10 cm[2*] (cal/cm^2)	Anode -Target Distance (cm)
1614	56	33	670	.93	580	174	55
1615	56	28	720	1.00	490	FFC	55
1616	54	26	700	1.06	510	170	55
1617	57	29	760	1.00	560	FFC	55
1618	58	30	750	1.03	540	DD	55
1619	56	30	760	1.02	520	179	55
1620	60	31	730	.94	600	121	65
1621	44	22	740	1.11	520	DD	65
1622	63	31	680	.86	600	125	65
1623	44	28	740	1.01	58	FLU	65
1624	63	40	730	1.07	600	110	65
1625	63	34	750	.98	560	DD	65
1626	55	29	690	1.01	520	115	65
1627	65	34	690	.92	580	DD	65
1628	61	33	750	.92	540	133	65
1629	62	35	750	1.03	550	DD	65
1630	66	35	720	1.04	540	120	65
1631	60	34	680	1.01	580	DD	65
1632	63	34	720	.94	580	BFD	65
1633	60	37	710	1.01	600	131	65

*FFC - Filtered Farady cup, DD - Depth-dose stack,
FLU - Fluence calorimeter (no data obtained),
BFD - Anode debris gauge.

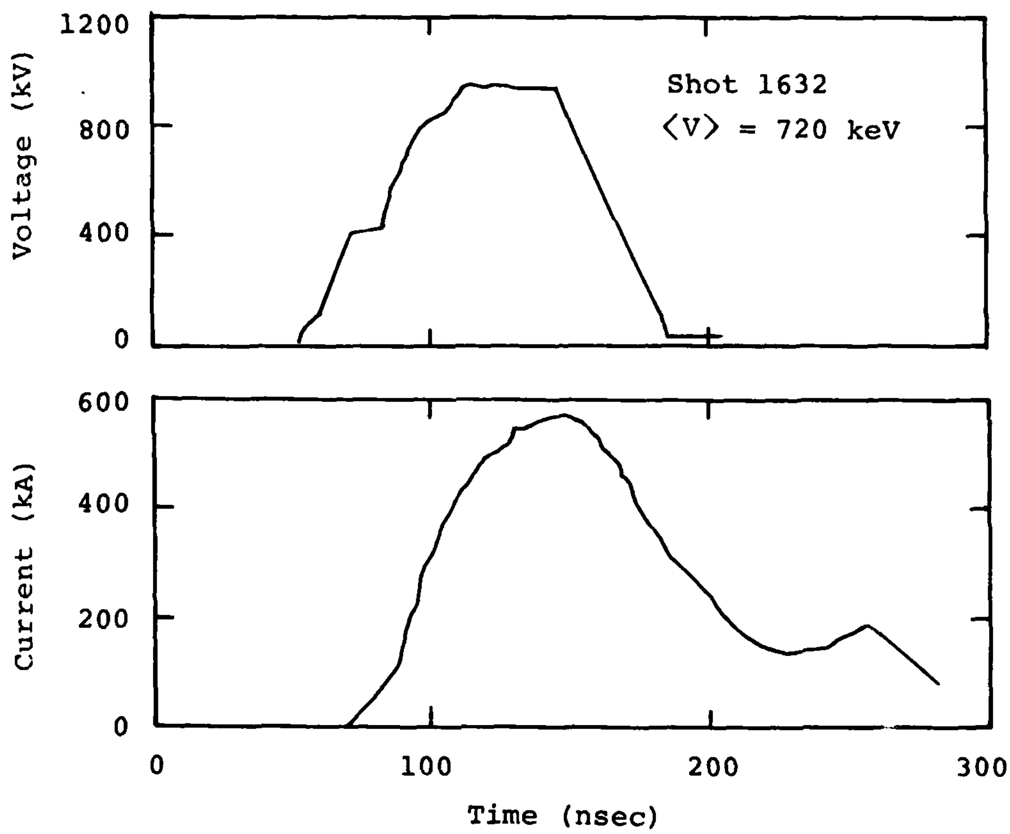

Figure 3. Representative Diode Data.

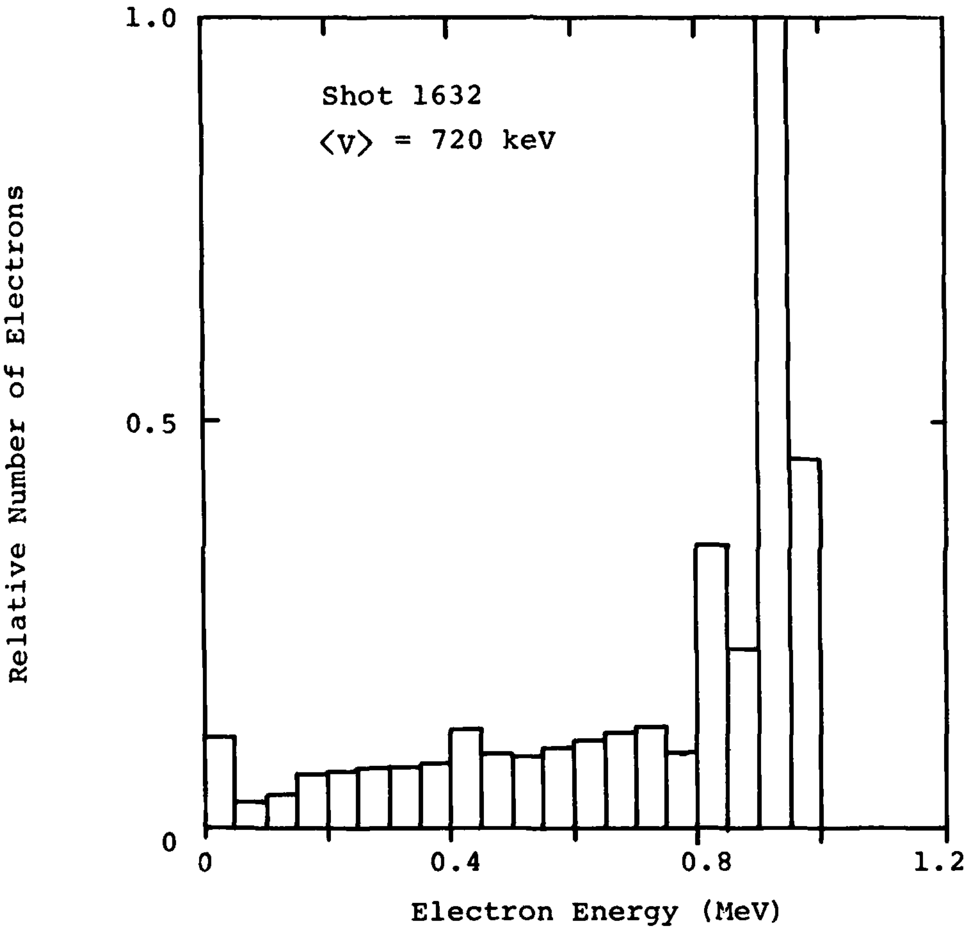

Figure 4. Representative Spectrum.

An approximately 3-cm^2 aperture was used to block anode debris and prevent breakage of the first thin calorimeter element. Some tests also used a 0.03-gm/cm^2 graphite cloth filter to prohibit element breakage.

Selected depth-dose data are given in Figures 5 and 6. The electron transport code ELTRAN was used by the AFWL to compute the depth-dose profiles in graphite from the electron spectrum as determined from the diode data for each shot. Best agreement with the measurements was obtained for a 30-degree incident angle as indicated in the figures.

A Faraday cup with multiple internal filters was used to determine the transmitted charge versus depth. This diagnostic technique has been recently developed for characterizing high dose pulsed electron beams.* Four points on the charge deposition profile are measured on a single test and used in conjunction with the spectrum determined from diode data and Monte Carlo electron transport calculations (i.e., ELTRAN) to determine the mean (or effective) angle of electron incidence. The energy deposition profile is then computed using the transport code and appropriate spectrum and incident angle.

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*K. Childers and J. Shea, A Faraday Cup with Multiple Internal Filters and a Primary Current Monitor for Characterizing High Dose Pulsed Electron Beams, AFWL-TR-76-132, Physics International Co., San Leandro, CA (1976).

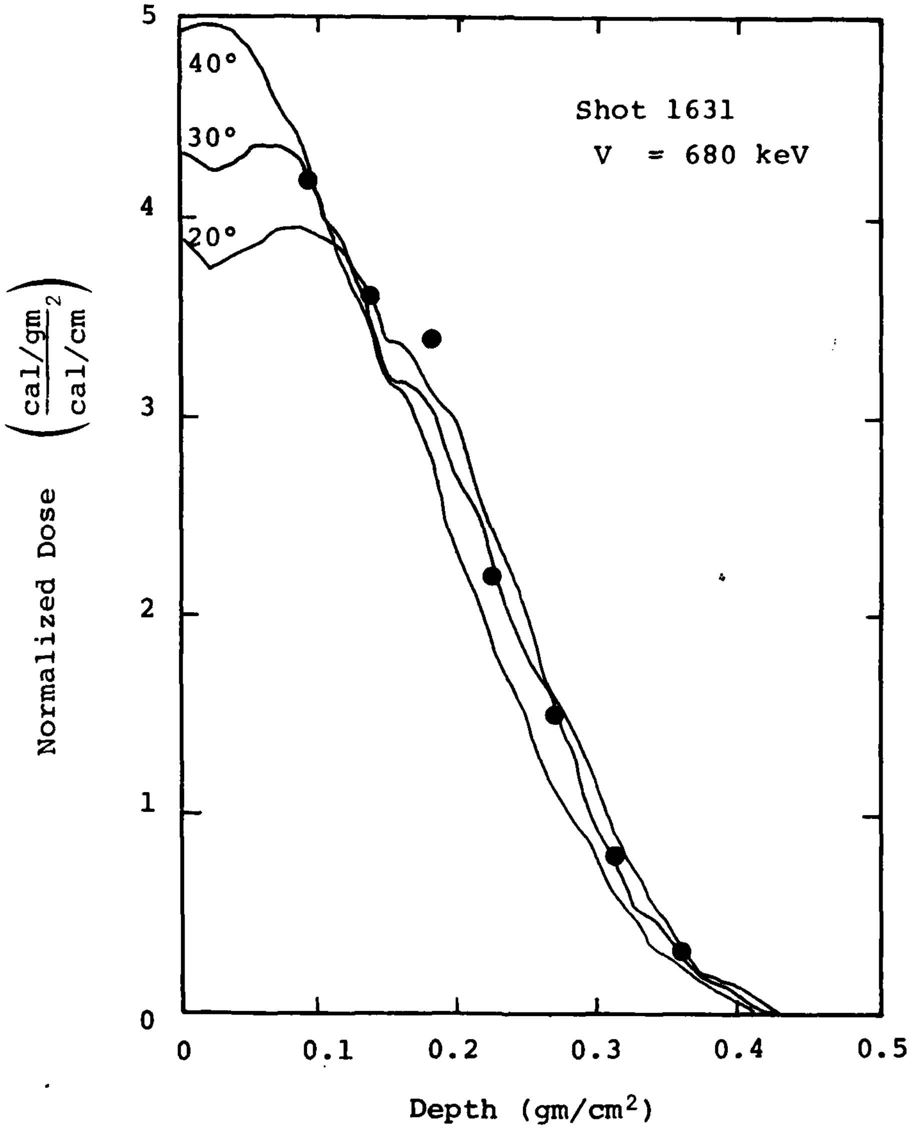

Figure 5. Depth-Dose Data for Shot 1631.

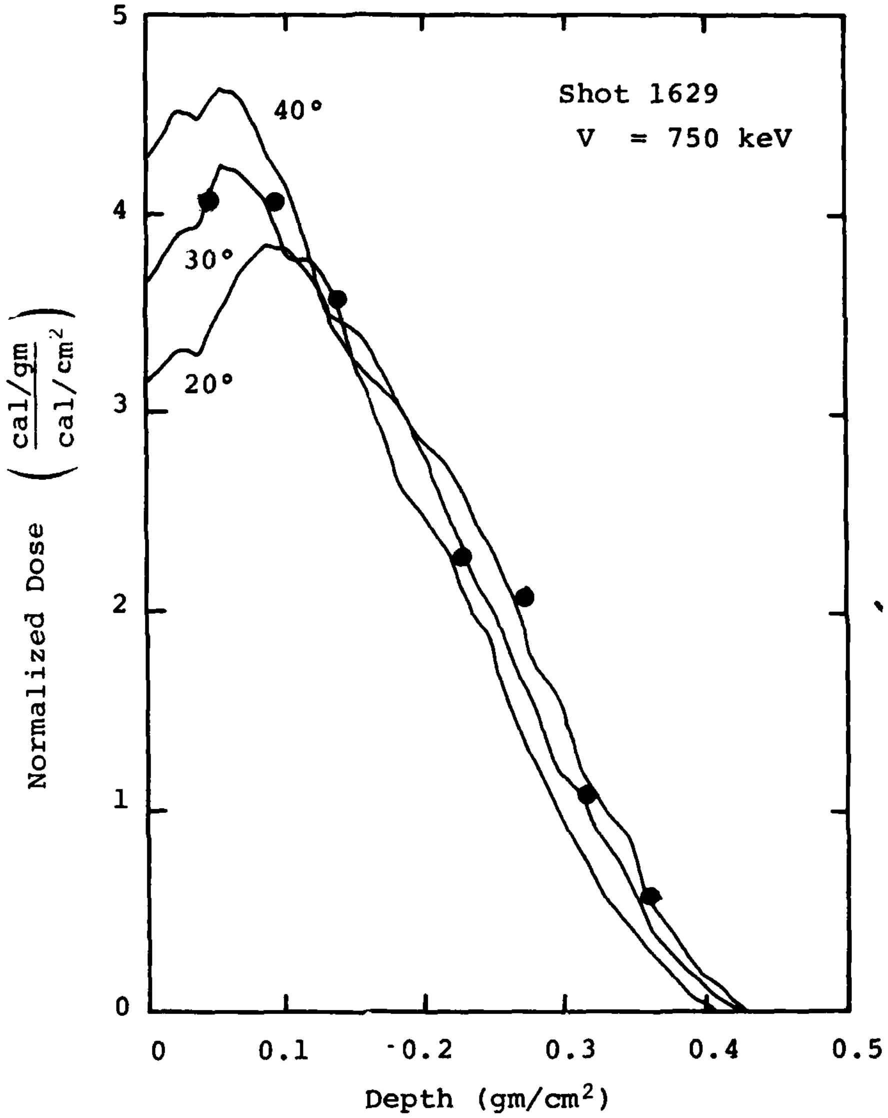

Figure 6. Depth Dose for Shot 1629.

Some difficulty was encountered in debugging this new diagnostic technique; however, reasonable data were obtained cn several shots, one set of which is shown in Figure 7. Integration of these current-time data yields the transmitted charge at each filter depth as given in Figure 8. Also shown in the figure are three transport calculations utilizing the spectrum determined from diode data for this test assuming incident angles of 20-,30-,and 40-degrees. Note that the transmitted charge data are plotted relative to the computed transmitted charge at F1.

Figure 8 illustrates the major difficulty in using the Filtered Faraday Cup technique to resolve depth-dose profiles for 1-MeV beams with relatively low incidence angles; that is, poor resolution of the effective angle from charge-depth data. Also, one places heavy reliance on the transport computer code (which incorporates over simplified transport physics with errors in the spectrum determination from diode data) to compute the depth-dose profile. The peak dose implied by the transport calculations shown in Figure 8 varies by $\pm$ 10 percent as the angle varies $\pm$ 10-degrees.

The fluence calorimeter consists of an array of nineteen 0.5-cm diameter cylindrical ATJ graphite elements placed in and thermally isolated from a graphite equilibrator. One element is on the beam axis and four elements each are on 1-cm, 2-cm, 3-cm, and 4-cm radii. Thermocouples are attached

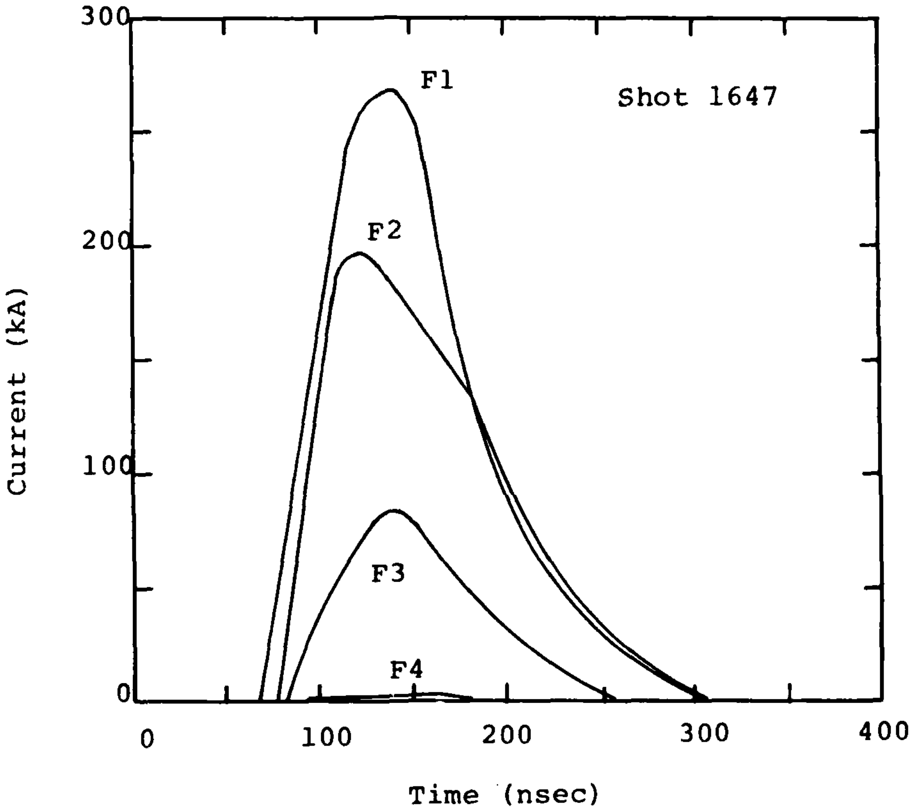

Figure 7. Transmitted Current Data.

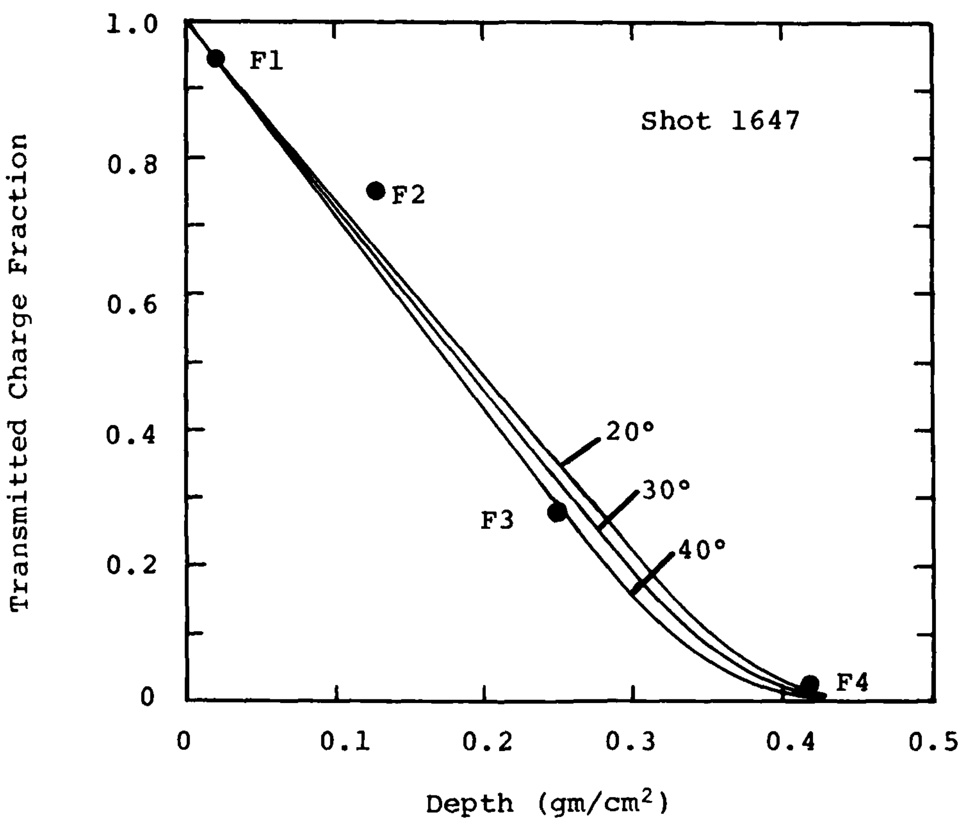

Figure 8. Transmitted Charge Data.

to brass pins pressed into the rear of each element, and the element temperature is determined by an exponential extrapolation of an analytic fit to the cooling curve (temperature-time). The fluence is determined from the temperature via the C_p relation previously given for ATJ graphite (with a small correction for the brass pin) and the effective element area (0.25-cm^2).

Fluence data were taken at two axial positions (anode-calorimeter distances), namely: 55-cm for the higher level and 65-cm for the lower level. Representative data for the low and high fluence levels are given in Figures 9 and 10, respectively.

To assess the shot-to-shot variations in fluence, the data from three consecutive shots are compared in Figures 11 and 12 for the low and high fluence positions, respectively. In these figures, for each shot, the data are averages at each radius. The relatively good agreement of the data indicates good average shot-to-shot reproducibility and suggests that the scatter in the data for a single shot is due to local "hot spots" in the beam. (The calorimeter element area is 0.25-cm^2.)

For general characterization purposes, the fluence data from each test are described by the average fluence over the central 10-cm^2 circular area (see Table 2). This fluence was determined by integration of an analytic fit to the data

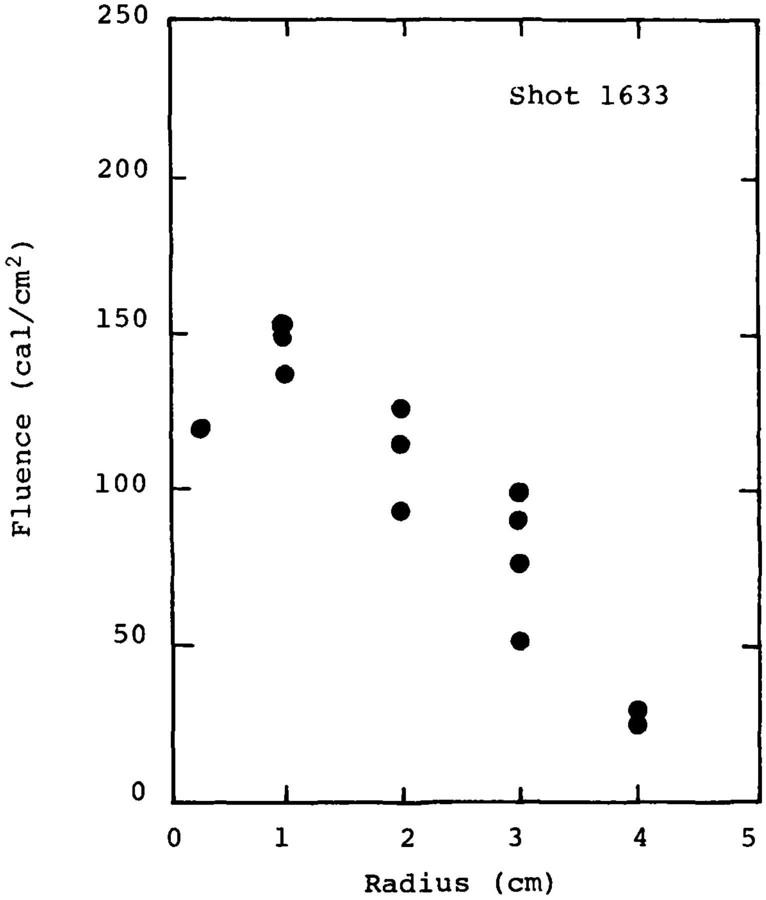

Figure 9. Representative Fluence Data, 122-cal/cm^2 Level.

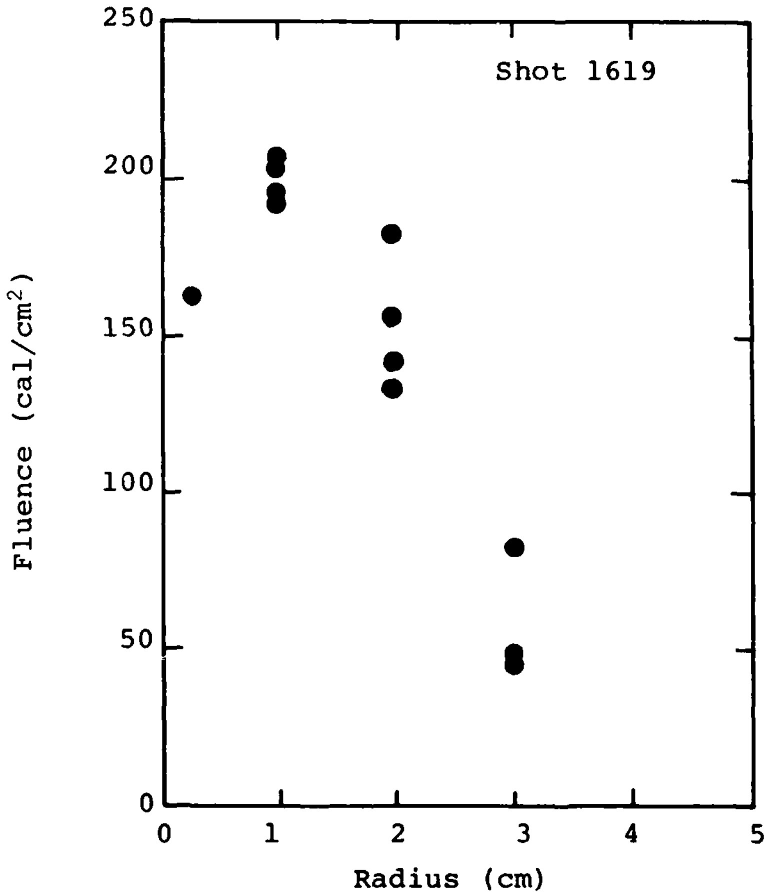

Figure 10. Representative Fluence Data, 174-cal/cm^2 Level.

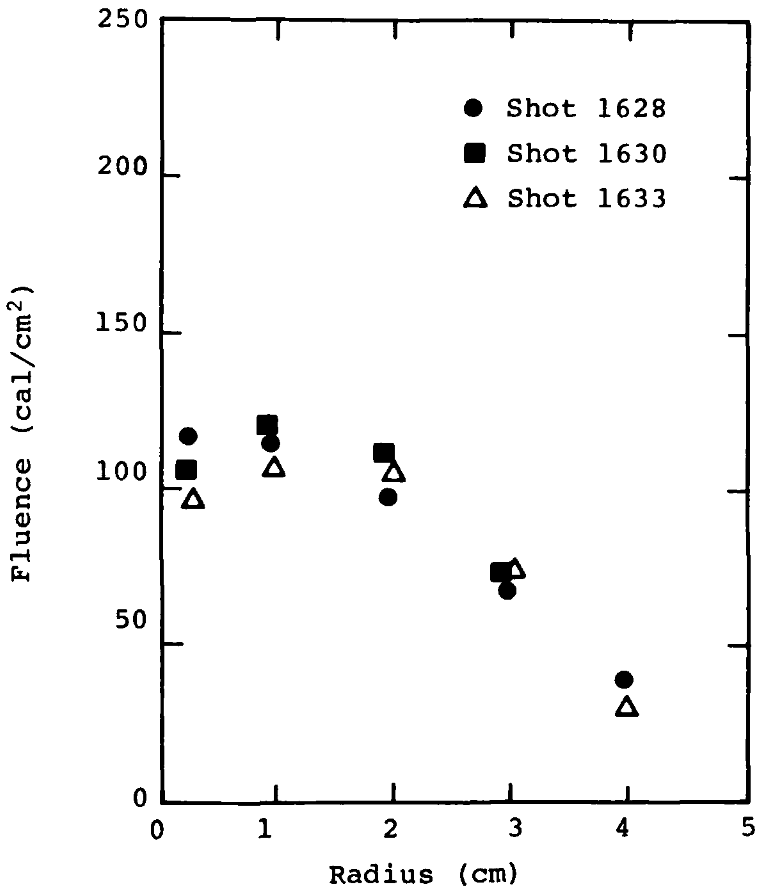

Figure 11. Data from Three Consecutive Shots, 122-cal/cm^2 Level.

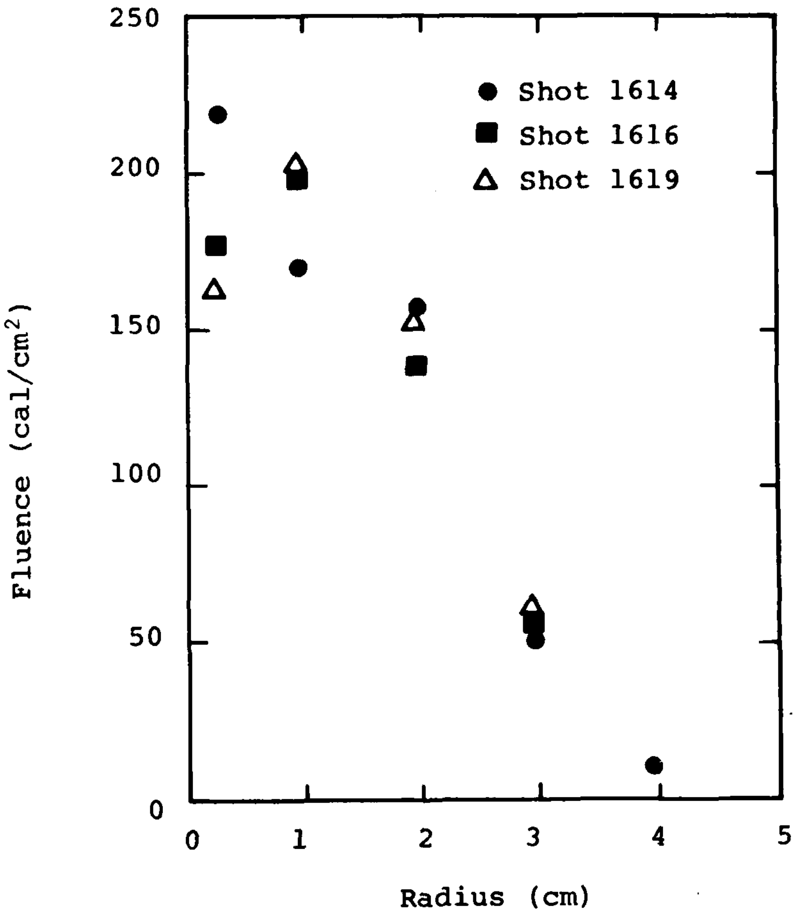

Figure 12. Data from Three Consecutive Shots, 174-cal/cm^2 Level.

at 0-,1-, and 2-cm radii over a 10-cm^2 area. The mean fluence over 10-cm^2 during the 20 shot series was 122-cal/cm^2 for the low fluence level (average of 7 shots), and 174-cal/cm^2 for the high fluence level (average of 3 shots).

A passive momentum gauge with a 10-cm^2 exposure area was used to make the anode debris measurements given in Table 3. A conical indentor and foam witness plate were used to measure the displacement of a pendulum. The pendulum axis was horizontal and perpendicular to the machine axis, and its mass was distributed such that it was inertially balanced for background motion along the machine axis (i.e., $\int rdm$ was equal above and below the pendulum axis). For material response tests an active impulse gauge would be mounted to an inertially isolated platform which would eliminate the machine vibration problem. Calibration tests proved the gauge to be sensitive to about 20-taps, with a resolution of $\pm$ 20-taps to 200-taps. Figure 13 displays calibration data for three impact test masses in which the indentor penetration is measured by rotation of a 32 pitch screw. The gauge sensitivity is 36-taps/turn.

Even though an attempt was made to inertially balance the pendulum, a background "impulse" of 60-taps was measured as a result of the test chamber motion with a graphite beam stop in front of the gauge. In order to determine impulse from the anode debris, this 60-tap background was subtracted from the measurements yielding an anode debris impulse of about 70-taps (see Table 3).

Table 3. Anode Debris Impulse Data

Shot	Anode	Impulse* (taps)
1632	1/4 mil mylar	60
1646	1/4 mil mylar	70
1649	1 mil titanium	70

*A 60-tap background impulse (measured on shot 1648) was subtracted from the measurement to obtain the anode debris contribution.

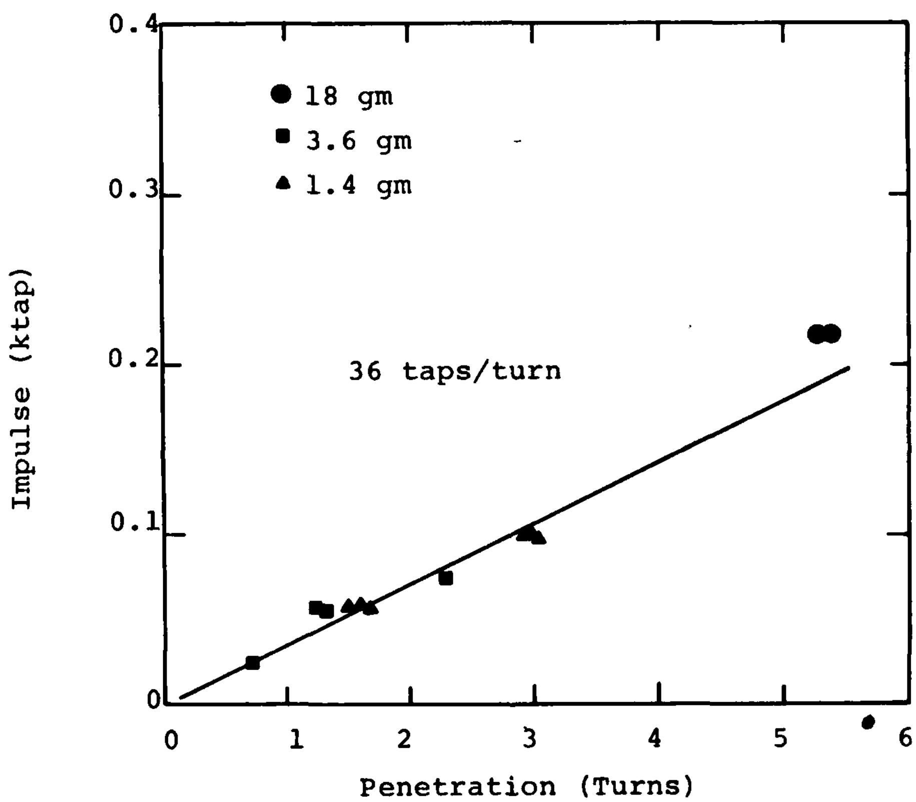

Figure 13. Impulse Gauge Calibration Data.

SECTION 3

CONCLUSIONS

Electron beams with peak accelerating potentials between 0.7-to 1.0-MV were characterized. The spread in peak potential was indicative of the several machine configurations investigated. The most consistent beam having the desired 1-MV peak accelerating potential was obtained with a 4-inch diameter cathode. After emission, the beam was magnetically compressed and was then adiabatically expanded in a decreasing axial magnetic field (peak field 24-kG). When expanded to the low fluence level (122-cal/cm^2), an effective electron incidence angle of 30-degrees was determined by fitting electron transport calculations to measured depth-dose profiles. This result is consistent with simple theory* which predicts a maximum angle of 40-degrees for this (3.3:1:2.3) compression and expansion. An average peak relative dose of 4.2-(cal/gm) / (cal/cm^2) was measured. At the higher fluence level (174-cal/cm^2, 3.3:1:1.5), a maximum angle of 55-degrees is calculated and an effective angle of 40-degrees estimated. Based on ELTRAN calculations, this increased incidence angle results in a 10 percent increase in the peak

*Young, T.S.T. and Spence, P., "Model of Magnetic Compression of Relativistic Electron Geams," J. Appl. Phy. Letters, 29, 464 (October 1976).

relative dose. Electron incidence angles much greater than 40-degrees are generally undesirable for material response applications because of their high peak dose, and difficulty in characterization.* The significance of this is that fluences greater than about 200-cal/cm^2 should be obtained via another machine configuration (e.g., smaller cathode) in order to maintain low incidence angle (i.e., cooler beam temperature or lower transverse energy).

Extremely good beam reproducibility was achieved over a twenty shot series as indicated in Table 4. The average deviation in peak diode voltage was five percent.

*Complications result in the characterization of the steeper-angle electron beams for a variety of reasons, among which are the properties of a bigger gradient or sharper drop-off in the energy deposition profile and the relatively high peak dose being too close to the surface.

Table 4. Summarized Statistics for Twenty Sequential Pulses, (1614-1633).

	Average	Mean Deviation
Peak Diode Voltage	.99 MV	5%
Peak Diode Current	560 kA	5%
Total Diode Energy	32 kJ	10%
Power Pulse Width (FWHM)	58 nsec	8%
Mean Electron Energy	720 keV	4%
Fluence* (3 shots at 55-cm)	174 cal/cm^2	2%
Fluence* (7 shots at 65-cm)	122 cal/cm^2	5%

*Average over $10\text{-}cm^2$.

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